7. THE RIO GRANDE DE TARCOLES, COSTA RICA

The basin of the Río Grande de Tárcoles is economically very important for Costa Rica. It includes the most populated and industrialized area of the country and the capital of San José. The basin also has highly productive agricultural zones and the river and its tributaries are important for hydropower production. The use of a runoff model will improve the possibilities to predict floods. It can also be used for long term forecasts of the water availibility during dry periods. Computations of design floods for hydraulic constructions and for flood risk maps are potential applications of a runoff model for the Río Grande de Tárcoles.

7.1 Basin description

The basin of the Río Grande de Tárcoles, see Figure 15, is situated in midwestern Costa Rica between 9°44′ and 10°11′ north latitude and 83°54′ and 84°40′ west longitude. The area of the basin at the outflow into Golfo de Nicoya of the Pacific Ocean is 2168 km^2. The river drains a broad depression which includes the western part of Valle Central (Central Valley) of Costa Rica. This valley is a densely populated region and the cities of San José, Heredia and Alajuela are situated in the basin.

The average altitude of the basin is more than 1000 m with decreasing levels from east to west. The landscape is irregular and flat zones are alternating with mountains, hills and canyons. The highest mountains are situated at the northeastern basin divide in the mountain range of the Cordillera Central with the volcanoes of Poás and Irazú as the highest peaks.

The Río Grande de Tárcoles is formed by the confluence of two main river branches, the Río Virilla and the Río Grande. The biggest is the Río Virilla, which drains the densely populated areas in Valle Central. Most of the tributaries to the two main branches rise on the slopes of the Cordillera Central.

The discharge of both the Río Virilla and the Río Grande is to some extent used for hydropower production. Via tunnels, canals and reservoirs water from the Río Virilla is conveyed to the power plant Ventanas Garita and from the Río Grande to the plant La Garita. Both plants release the water into the Río Grande near the confluence with the Río Virilla. The regulation capacity is small and the reservoirs cannot be used for flood damping.

Due to population increase and industrial development the basin has lost most of its original vegetation. Especially in Valle Central there has been advanced deforestation and the forests are replaced by agricultural fields, grasslands and urban areas. Most of the forests that exist are located near the northeastern divide in the Cordillera Central and in the southwestern part of the basin. Above an altitude of 1500 m in the Cordillera Central the forest can be caracterized as a humid type and in the rest of the basin as dry forest. Large areas of coffee plantations are situated in the basin and it is the most productive coffee-zone of Costa Rica. Other important crops are sugar cane, corn and cereals. The basin also has a well developed dairy industry.

The deforestation, the intense agriculture and the urbanization have brought about serious erosion in the basin. Besides land use problems it has given heavy sediment loads in the rivers. The sediments are a major problem in relation to hydropower production.

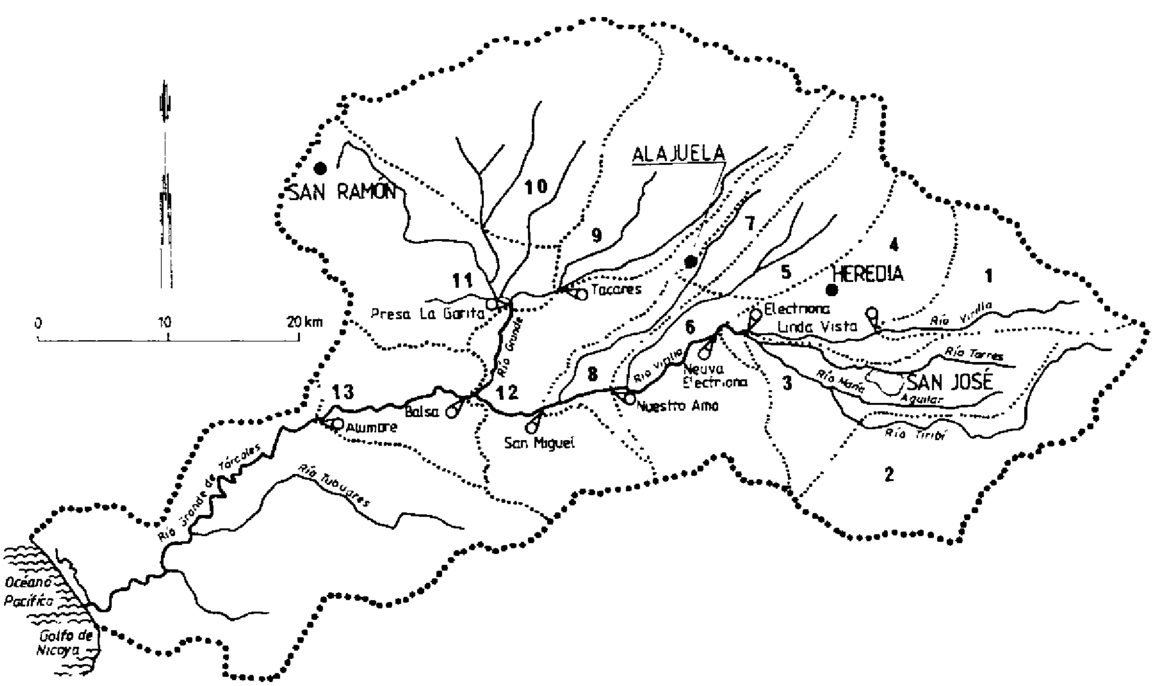


Figure 15. The basin of the Río Grande de Tárcoles.

The basin of the Río Grande de Tárcoles is influenced by the intertropical convergence and has a rainy season from May to October and a dry one from December to March. April and November are transition months, which are characterized by an alternation of wet and dry periods. In July or August the rainy season has a recession, called "veranillo" during which conditions of the dry season are experienced. The start of this recession varies from one year to another and it can last from some days to several weeks.

The Cordillera Central at the northern basin divide is an obstacle for northerly winds in the lower atmosphere. However, the depression of La Palma between the Irazú and Barva volcanoes allows the influence of the Caribbean rainy regime in December and January. This influence is associated with the displacement of cold fronts from higher latitudes. The cold fronts produce drizzle and moderate rain in the Valle Central, phenomena known as "temporales". The periods of continuos rain caused by the "temporales" can sometimes produce floods.

Annual precipitation of more than 3000 mm occurs along the northern basin divide and in an area in the southwestern part of the basin. Least precipitation with about 1800 mm annually has the central area of the basin. The mean annual precipitation in San José is around 1900 mm and 335 mm of that fall in September which is the rainiest month.

The temperature has low seasonal variation with less than 5 °C between the highest and lowest monthly mean values. The annual average of daily maximum temperature varies from 30 °C in the coastal zone to 26 °C in San José and about 15 °C in the mountain regions. Corresponding values for the daily minimum temperature are 20 °C, 15 °C and 5 °C.

The trade winds predominate throughout the year. In general the maximum wind speeds occur during the dry season and the "veranillo". The relative humidity is around 80 % during the whole year.

7.2 Flood history

In the region of San José, there are frequent flood problems. The upper Río Virilla and its tributaries Río Torres, Río María Aguilar and Río Tiribí often overflow. The main part of the floods occur during the rainy season and most frequently in October, but some floods occur in December - January associated with cold fronts from the north. The most recent severe flood was caused by the tropical hurricane Joan (Juana) in October 1988. There are also occasional flood problems in other parts of the basin and a region with relatively frequent floods is the lower reach of the Río Grande de Tárcoles. The floods cause inundations of both rural and urban areas and the main damages occur in residential districts and industrial zones.

7.3 Model set-up

The HBV model has been adapted for the upper 80 % of the basin of the Río Grande de Tárcoles. That means an area of 1745 km^2 upstream from Alumbre. For the model computation the basin of the river has been divided into 13 subbasins, se Figure 15. Nine of these subbasins have outlets at existing or former streamflow stations. The other subbasins were created in order to get fairly homogeneous regions as regards altitude, vegetation and precipitation.

Streamflow forecasts are mainly of interest at the outlets of the subbasins no 3, 6 and 13. At these points the streamflow stations Electriona, Nuestro Amo and Alumbre are located respectively. For Electriona the forecasts will give an indication of the flood risk in the San José urban area. At Nuestro Amo the forecasts are important for the management of the intake gates to the power plant Ventanas Garita. The reason is that garbage and other debris is carried by the river at rising water stage and can interrupt the production. Forecasts for Alumbre give information about flood risk in the lower reach of the Río Grande the Tárcoles.

The model has been calibrated on streamflow data for the stations Electriona, Nuestro Amo, San Miguel, Tacares, Presa la Garita, Balsa and Alumbre. Their respective total basin areas are 302, 734, 829, 202, 649, 1638 and 1745 km^2 with annual mean discharge of 12, 27, 36, 13, 35, 78 and 81 m^3/s.

The basin has a relatively dense precipitation network although not uniformely distributed, and few stations are located in the higher parts of the mountains. The weights for the stations were calculated by Thiessen polygons but with subjective modifications. Some effort was spent on adjusting the weights in order to increase the accuracy of the model simulation.

A network of seven telemetric precipitation stations is under installation in the upper part of the basin. These stations will facilitate the collection of precipitation data for real-time forecasting with the HBV model. They will also make it possible to forecast shorter intervals than one day.

Potential evapotranspiration for the basin has been calculated by the IMN of Costa Rica using the Penman formula. The monthly mean values used for the model computations are shown in Table 3. These values represent the central part of the basin.

Table 3. Monthly mean values of potential evapotranspiration (mm/day) according to the Penman formula.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.0	4.7	5.2	5.0	4.0	3.5	3.5	4.0	3.7	3.5	3.5	3.7

7.4 Calibration results and forecasts

The HBV model for the Río Grande de Tárcoles was first calibrated with daily computation time-steps. The calibration period was 1972-1986 and data from 36 precipitation stations and 7 streamflow stations were used. The model-run results for 1984 at Alumbre are shown as an example in Figure 16. The model parameters are listed in Appendix 5. The year 1984 was one of the rainiest, but also a year for which the model simulation succeeded relatively well.

The calibration results are as a whole acceptable, but there seems to be a possibility for improvement. The weights of the precipitation stations is one factor that could be further considered. It seems that precipitation near the basin divide in the Cordillera Central is not always well represented. Another factor is the great variability of the response time. Some parts of the basin, for instance subbasin 9, react very slowly on precipitation, while other parts react quickly.

For the period immediately before a forecast, collection of precipitation data cannot be done for all the 36 stations, but only from those that can be reached by telephone. Therefore, forecast model versions using data from fewer precipitation stations are needed. Special care must be taken to include good and representative stations near the northern and eastern parts of the basin divide.

For the Río Virilla in the upper part of the basin, real-time input data are to be measured with the telemetric precipitation network that is under installation. This network covers the uppermost 6 subbasins down to the streamflow station Nuestro Amo. The forecast version of the model for this part of the basin has been calibrated on data from the seven precipitation stations that most closely correspond to the telemetric stations. The result has up to now not been quite as good as with all stations but the calibration can probably be improved. The results of the calibration will also give an indication whether the telemetric stations give a good representation of the areal rainfall or if any station should be relocated.

The model for the Río Virilla is also being adapted for 6-hours time-steps in order to get earlier predictions of the floods. Precipitation and streamflow data have been prepared on 6-hours intervals for the years 1983 and 1984 and some calibration has up to now been carried out. The model parameters that affect the time distribution of the flow are to be changed in this calibration, while the others are to be left the same as in the calibration on daily data.

The procedure of real-time forecasting has been tested with daily data. In November 1989 short and long range forecasts were made for Nuestro Amo. Precipitation data for the last days before the forecast were collected from 3 stations. Streamflow data could not be collected and therefore updating of the model was not considered. No meteorological forecast was available but 3 possible precipitation sequences were used as input data for a short range forecast of 5 days. Forecasting for the whole basin was later done with data from 11 precipitation stations.

Operational real-time forecasting for the Río Virilla will be possible thanks to the recently started telemetric transfer of precipitation data. This transfer also allows forecasting with the model version for 6-hours time-steps. A procedure for collection of streamflow data should be introduced in order to make updating of the model possible. Precipitation data for the immediate future should be taken from a quantitative precipitation forecast or at least be estimated by an experienced meteorologist.

The telemetric network only covers the basin of the Río Virilla. Further downstream in the Río Grande de Tárcoles operational forecasting require input data from additional precipitation stations. Data from these stations have to be collected by telephone or radio.

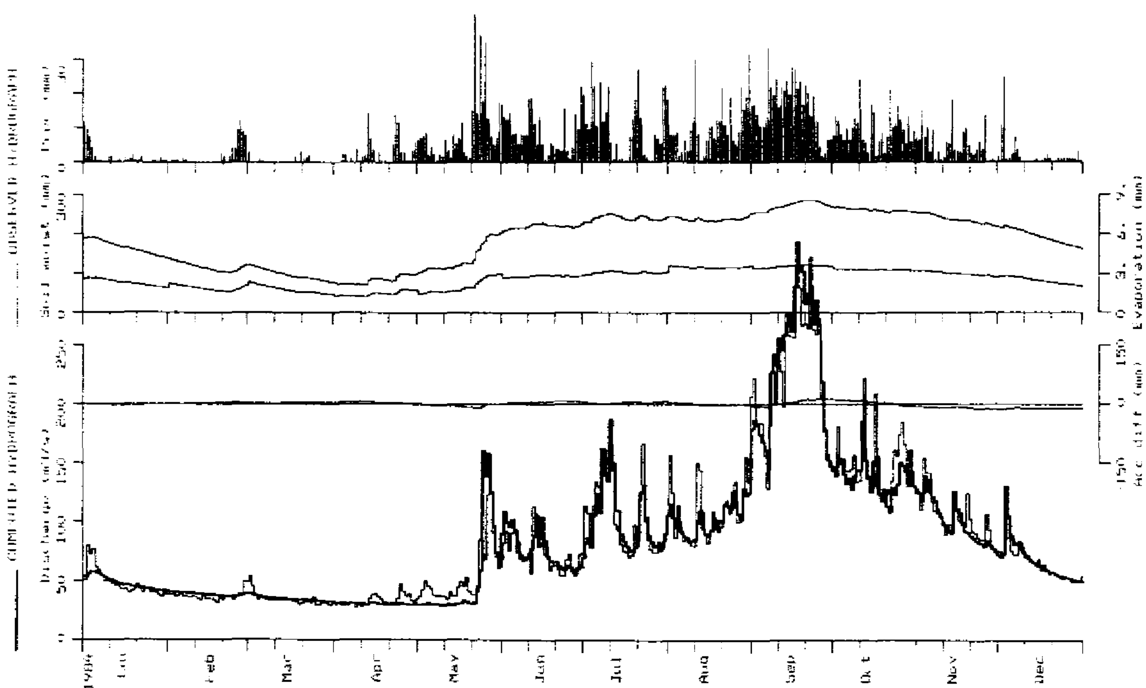


Figure 16. Model results in 1984 for Alumbre.

8. THE RIO BAYANO, PANAMA

The Río Bayano is one of the biggest and most important rivers in Panama. It has been regulated since 1976 for hydropower production and has a water reservoir with a considerable storage capacity. About 20 % of the electricity production in Panama is generated by the river. A forecast system for the river can be used for a better management of the regulation reservoir, which can both increase the hydropower production and decrease the risk for floods downstream from the reservoir. The forecast will also increase the possibilities to issue flood warnings when necessary.

8.1 Basin description

The basin of the Río Bayano, see Figure 17, is located in the eastern part of the Panamanian isthmus, between 8°48′ and 9°23′ north latitude and 78°04′ and 79°16′ west longitude. The headwaters of the river are in the hills that separate the provinces of Panama and Darién. The northern basin divide follows the Serranía de San Blas, that separates the basin from the narrow strip of wetland that borders the Caribbean Sea. To the south the basin is limited by the mountains in the Serranía de Majé. In the central part of the basin the reservoir Lago Bayano has been constucted.

The Río Bayano follows a general east to west direction, meandering for approximately 215 km. It pours its water into the Pacific Ocean and has a basin area of about 5000 km^2. The central part of the basin is relatively flat. The areas close to the river have deep alluvial deposits and the main part of the basin is formed by sedimentary rocks. The mean elevation is 267 m and the average slope is 0,4 %. The highest peak is Cerro Chucanti in the southwest with an elevation of 1300 m.

The basin is still to a large extent covered by forests, especially upstream from the Bayano dam where primeval forests cover about three fourths of the area. The primeval forests are most predominant north of the reservoir and near the southern basin divide. The rest of the land is covered by a mixture of bushes, secondary forests, cattle raising pastures and agricultural fields.

The basin population is about 23000 inhabitants of which approximately

10 % are indigenous to the area. The population cultivates mainly for subsistence using the traditional method of slash and burn. Downstream from the dam there are commercial plantations of corn, rice and plantains and also cattle is raised for commercial purposes.

The conditions for soil erosion are very different in the southern part of the basin compared to the northern part. That is caused both by geology and vegetation cover. The most susceptible regions for soil erosion are located in the southern and western parts, which have suffered most changes with respect to the natural conditions, and there a fast rate of erosion due to human activities can be observed.

There are great differences in the runoff between different parts of the basin. The northern tributaries have highest runoff since their headwaters are in the Serranía San Blas, which is one of the most rainy areas in Panama. Their runoff is almost 100 $l/s^x km^2$, while the southern tributaries have runoff values ranging from 50 to 85 $l/s^x km^2$. The lowland area between the mountain ranges has a runoff of 30-35 $l/s^x km^2$.

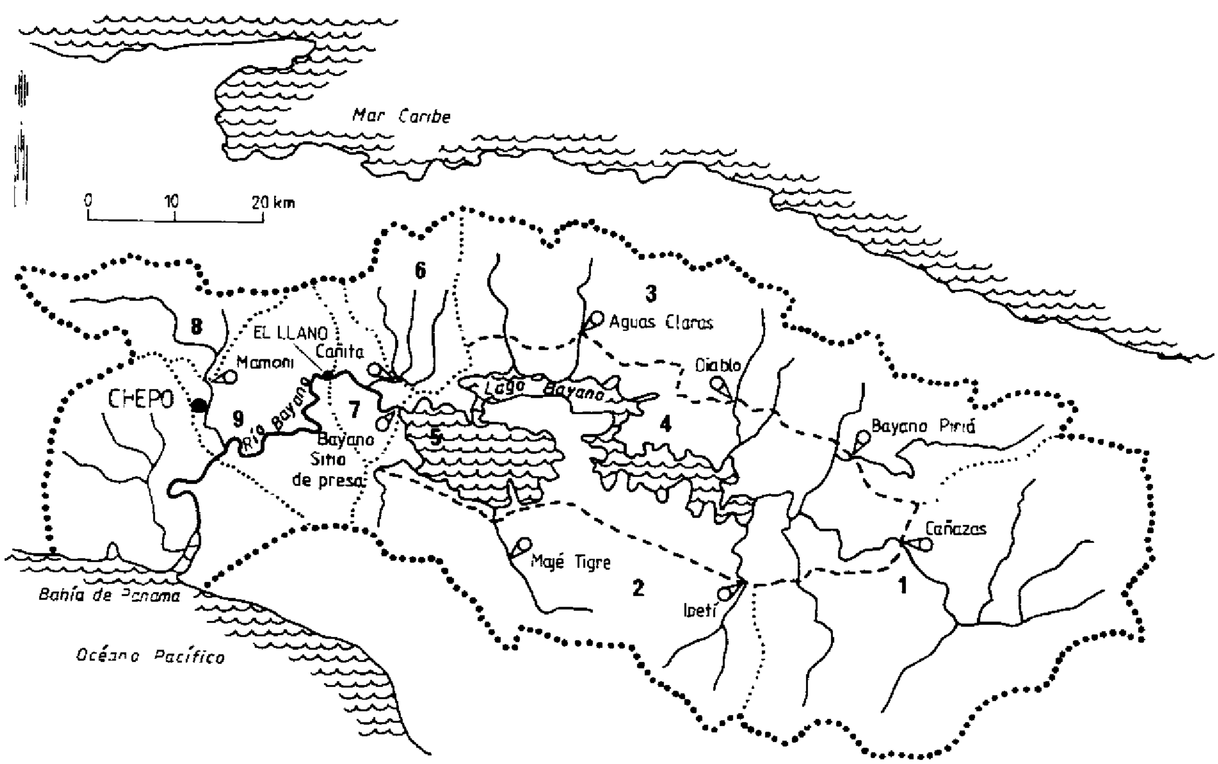


Figure 17. The basin of the Río Bayano.

The construction of the civil structures of the hydropower plant started in December 1971 and the closing of the gates was on the 16th of March 1976. The reservoir Lago Bayano has, at its maximum level 62,5 m, an area of about 360 km^2. The maximum regulation volume is 3100 millions of m^3 and the reservoir is used for the annual regulation of the discharge for electricity generation. About 4700 millions of m^3 water are turbinated annually and the mean discharge amounts to 150 m^3/s.

The Río Bayano basin is influenced by the intertropical convergence zone which is characterized by irregular winds of different intensity with frequent and strong precipitation. Towards late April, when the northern trade wind intensity diminishes, the intertropical convergence zone arrives to Panama, on its way up north, producing the rainy season which ends in late December. The maximum amount of precipitation falls in October and November. In January, when the northern trade winds dominate and move the rain strata toward the southern hemisphere, the dry season begins. In the mountain ranges of the basin it is not so severe and showers are frequent the whole year.

The average annual precipitation in the basin is around 2500 mm. The maximum precipitation takes place in the northern part of the basin and there are areas near the basin divide where the annual precipitation has been estimated to be more than 5000 mm. Minimum precipitation falls in the central part of the basin, where the annual amount is less than 2000 mm. The average annual temperature is approximately 25 °C and the seasonal temperature variation is insignificant. The mean relative humidity is around 85 %.

Using Thornvaite climate classification, 60 % of the basin has humid megathermal climate without humidity deficit, 30 % is perhumid megathermal and the remaining 10 % is perhumid mesothermic. According to the Holdridge system the Bayano basin has been classified as a wet tropical forest which overlaps with the dry tropical forest characteristics.

8.2 Flood history

The lower reach of the Río Bayano is surrounded by low-lying areas that are susceptible to floods. The town of El Llano located 56 km from the river mouth and a number of villages along the river are exposed. There are also fields with comercial plantations of corn, rice and plantains that are threatened by inundation. The flood problems are sometimes made worse by high sea level. In the river mouth the tide can be up to 6 m and influence the water level the whole way up to El Llano.

Before the construction of the reservoir Lago Bayano, the river flooded the low-lying areas frequently and at El Llano flood problems appeared on an average every second year. The last times that severe floods occured were in October 1975 and in November 1966 when the rising water of the Rio Bayano and its tributaries the Río Mamoni and the Río Majecito caused big damages.

Since the regulation was taken into use there has not been serious flood problems. However, the risk for flooding has not been eliminated. Flood problems will under the present conditions occur mainly when the reservoir is full and a heavy rain causes a great inflow that must be spilled at the same time as the discharge is high in the tributaries downstream from the reservoir. During the last years the risk has somewhat increased, caused by changes in operation of the reservoir in order to keep a high water level, which is more advantageous for the power production.

8.3 Model set-up

The HBV model for the Río Bayano has been set up as two applications - one for computing the net inflow to the reservoir and the other one for computing the discharge in the lower reach of the river. The purpose for the first application is to make forecasts in order to improve the management of the reservoir for the hydropower production. The second application is to be used for forecasting floods and has a routine that estimates the spill according to a probable operation of the gates.

The basin of the reservoir Lago Bayano has in the model been divided into five subbasins. The division has been made with the intention of creating as homogeneous areas as possible, especially for precipitation. Subbasin 1 is formed by the easternmost part of the basin, which is mainly lowland covered with tropical forest. Subbasin 2 consists of the mountain slopes south of the reservoir and is to some extent affected by human activities.

The forest covered mountain slopes north of the reservoir form subbasin 3 and the lowland area around the reservoir is subbasin 4. Finally subbasin 5 is formed by the reservoir.

The calibration of the model has been carried out on inflow data for Lago Bayano. These data have been calculated from discharge at the power plant including spill and the change of water level in the reservoir. The behaviour of the model for the three first subbasins has been checked against streamflow data from stations in these areas. For subbasin 1 it is the station Cañazas with a basin area that covers 69 % of the subbasin. The stations Ipetí and Majé Tigre together cover 46 % of subbasin 2 and Bayano Piría, Diablo Ante Embalse and Aguas Claras 41 % of subbasin 3.

The basin area downstream from Lago Bayano has been divided into four subbasins of which two correspond to the catchment areas of streamflow stations in the tributaries. They are subbasin 6 for the Río Cãnita and no 8 for the Río Mamoní. Subbasin 7 has its outlet at the flood susceptible town of El Llano and no 9 downstream of the Rio Mamoni. The model behaviour for the two subbasins with streamflow data has been calibrated. Since there are no streamflow data for the lower Río Bayano, the model parameter values for the two remaining subbasins had to be guessed.

The precipitation network in the Río Bayano basin is sparse and all stations are located at relatively low altitude. Some stations have data records of low quality and there are many periods with missing data. Initially 15 precipitation stations were selected but already before the calibration 4 were excluded mainly due to homogeneity problems.

For each subbasin a number of stations were chosen to represent the precipitation. The initial weighting had to be very subjective due to the spatial distribution of the precipitation stations. For the subbasins 3, 6 and 8 all the stations were located outside or at the border of the subbasin. During the calibration some effort was spent on adjusting the station weights by trial and error.

At seven streamflow stations around Lago Bayano there is equipment for telemetric real-time transmission of data via satellite. These stations also measure and transmit precipitation data. In most cases the telemetric stations are located relatively close to the ordinary precipitation stations and give approximately the same rainfall as these. Even if it is considered that most of the telemetric stations have worked relatively well, they have a lot of missing data and are therefore not suitable for calibration of the model. However, they provide input data in a forecast situation.

Potential evapotranspiration for the basin has been calculated from earlier evaporation measurements carried out in the basin of the Río Bayano. At a place that is now inundated by the reservoir the evaporation from a Class A pan was observed during the period 1963-1972. These values were compared to evaporation measurements from a lake pan in Lago Gatún in the Panama Canal Zone and monthly correction factors were calculated. Using these correction factors the records for the Class A pan were extended until 1988. The average values of the old and new period were calculated and used as potential evaporation input to the model.

8.4 Calibration results and forecasts

The HBV model for the Río Bayano has been calibrated on data records from the period 1977-1988. For the application for Lago Bayano data from 8 precipitation stations were used and altogether 11 stations for the whole basin. An example of the model-run results for Lago Bayano is shown in Figure 18. The model parameters are listed in Appendix 6. The year of 1988 has been chosen for the example, since it is the most recent year with complete data. It is also the only year after 1981 with spill from the reservoir. This spill was caused by the hurricane Joan (Juana), which passed north of Panama but nevertheless gave rain in the basin of the Río Bayano.

The recorded hydrograph in Figure 18 is calculated from water level and discharge data. A small error in the recorded water level results in big errors in the calculated inflow, which cause apparent inflow changes, that in fact should be distributed over many days. Thus, the model shall not simulate these fluctuations but give an average curve through them.

The model simulation for Lago Bayano is acceptable when one takes into consideration the distribution of precipitation stations. All the stations are located around the reservoir and no station is situated in the areas with high precipitation. For 1988 the model underestimates the inflow during the end of the dry season and the reason is probably rain in areas without precipitation stations.

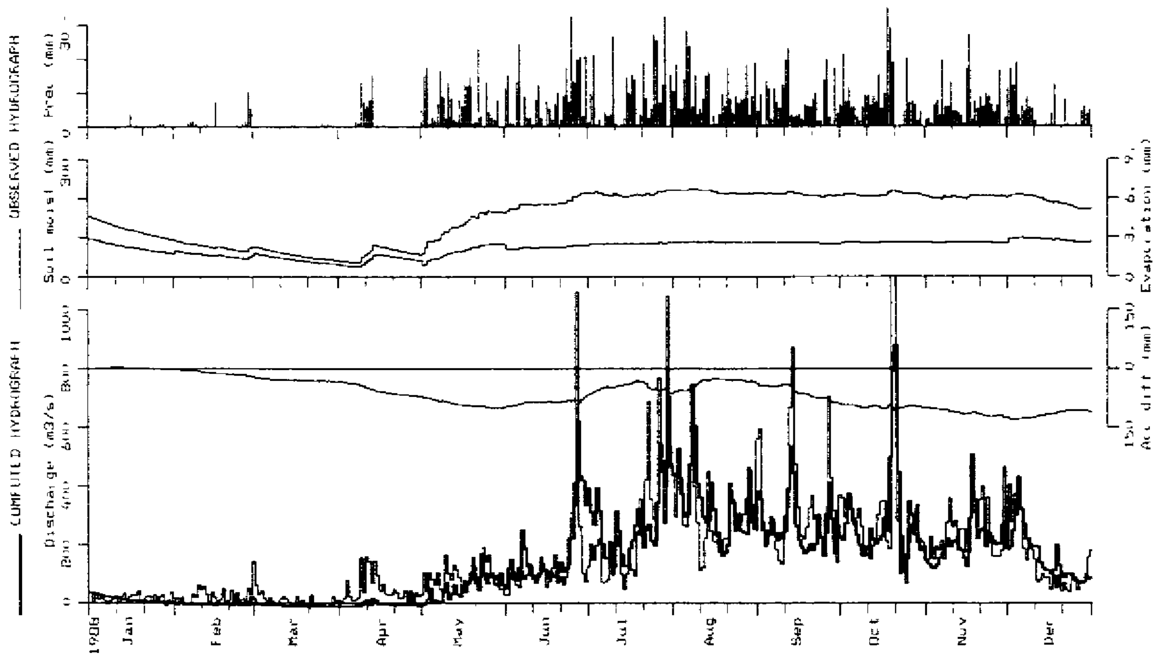


Figure 18. Model results in 1988 for the inflow to Lago Bayano.

The data transmission from the telemetric network is not always working for all stations. In order to find out how much missing data deteriorate the model performance, recalibration has been carried out with a decreasing number of precipitation stations. This was done by removing the stations one by one, always keeping the most reliable ones in the model. Figure 19 shows that with 5 stations the model performance is almost as good as with all stations. The result indicates that the present network in the lowland areas around the reservoir is sufficient. Additional stations should be located in more remote areas closer to the basin divide.

The procedure of real-time forecasting was tested in November 1989 and both short range and long range forecasts were made. The telemetric network provided precipitation data for the last two months before the forecasts.

A short range forecast for seven days is shown as an example in Figure 20. The model was updated before the forecast. Since no meteorological forecast was available, three possible precipitation sequences were used. These sequences were 0, 10 and 20 mm each day. The first sequence gave decreasing inflow to the reservoir, the second almost unchanged inflow and the last one increasing inflow.

A long range forecast was made to April 15, that is to the end of the dry season. Precipitation data from the corresponding dates during the period 1977 to 1988 were used as input. The result of the 12 different simulations with tabulated values of the highest peak for each simulation is shown in Figure 21. The forecasted accumulated volume is given in Figure 22.

Operational real-time forecasting of the inflow to the Lago Bayano can be started at any time. A quantitative forecast of the areal precipitation should be provided as input for taking full advantage of the short range forecast. If no regular meteorological forecast is available, a qualified estimate by an experienced meteorologist could be used.

Forecasts of the flow in the river reach downstream from the reservoir require real-time data from at least one precipitation station in that part of the basin. The collection of these data could be done by telephone. Operational forecasting in this area is useful only during periods with flood threats.

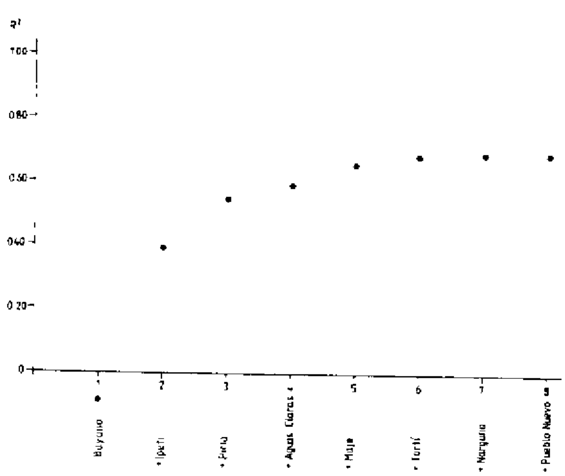
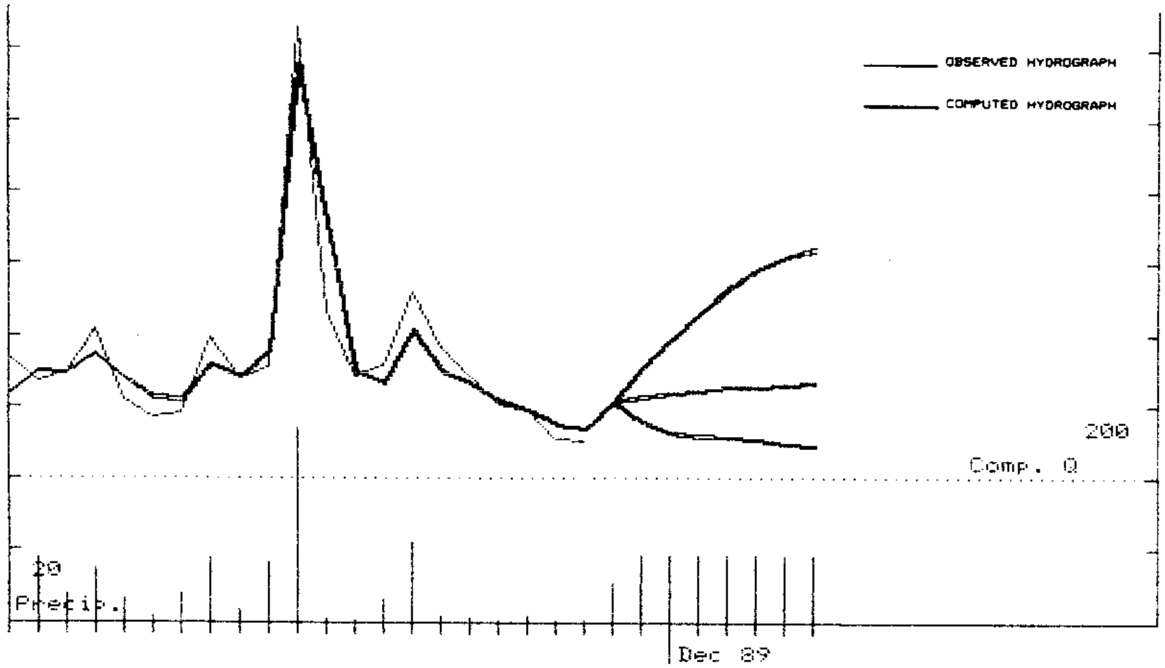


Figure 19. Model performance for the inflow to Lago de Bayano versus number of precipitation stations.



FORECAST 1

DATE	Precip.	Soilmois	Upp.zone	Low.zone	Comp. Q	Rec. Q	Acc.dif	Evap.	Pcorr
891130	0.0	202.4	0.8	50.1	156.9			2.6	
891201	0.0	199.5	0.0	47.8	127.5			2.9	
891202	0.0	196.6	0.0	44.9	114.2			2.9	
891203	0.0	193.8	0.0	42.3	106.9			2.9	
891204	0.0	190.9	0.0	39.7	100.1			2.8	
891205	0.0	188.1	0.0	37.3	93.6			2.8	
891206	0.0	185.4	0.0	35.1	87.6			2.8	

BASIN: BAYANO MONTH: Nov 1989

FORECAST 2

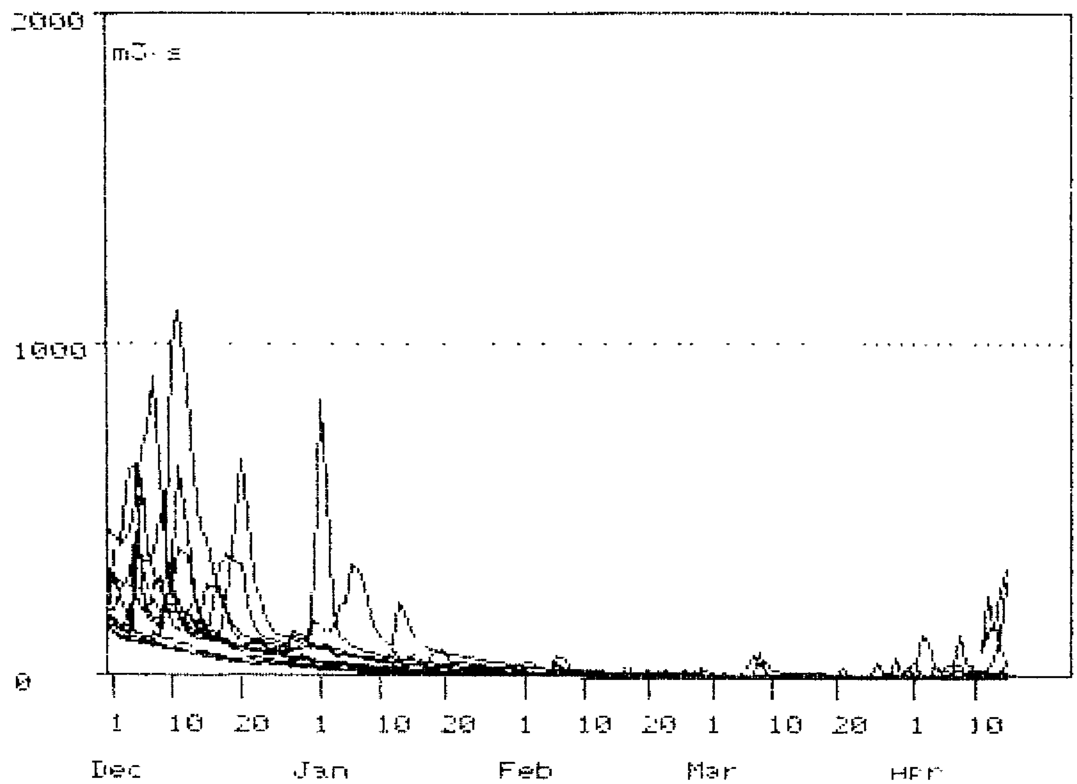
DATE	Precip.	Soilmois	Upp.zone	Low.zone	Comp. Q	Rec. Q	Acc.dif	Evap.	Pcorr
891130	10.0	205.8	4.0	52.0	223.9			2.6	
891201	10.0	206.1	4.5	52.6	233.7			2.9	
891202	10.0	206.4	4.9	53.1	242.0			2.9	
891203	10.0	206.7	5.2	53.7	248.6			2.9	
891204	10.0	206.9	5.4	54.2	253.9			2.9	
891205	10.0	207.2	5.6	54.6	258.4			2.9	
891206	10.0	207.4	5.7	55.1	262.1			2.9	

BASIN: BAYANO MONTH: Nov 1989

FORECAST 3

DATE	Precip.	Soilmois	Upp.zone	Low.zone	Comp. Q	Rec. Q	Acc.dif	Evap.	Pcorr
891130	20.0	208.8	8.8	52.0	303.8			2.7	
891201	20.0	211.7	13.1	52.6	382.6			3.0	
891202	20.0	214.1	15.8	53.1	455.1			3.0	
891203	20.0	216.0	17.4	53.7	528.1			3.0	
891204	20.0	217.6	18.2	54.2	576.0			3.0	
891205	20.0	219.0	18.4	54.6	611.1			3.0	
891206	20.0	220.1	18.5	55.1	634.9			3.0	

Figure 20. An updated model simulation of the inflow to Lago Bayano followed by a 7-day forecast commencing 1989-11-30. Three alternatives of input data were used for the forecast.



Forecast 1989 11 30 using data from the 12 previous years

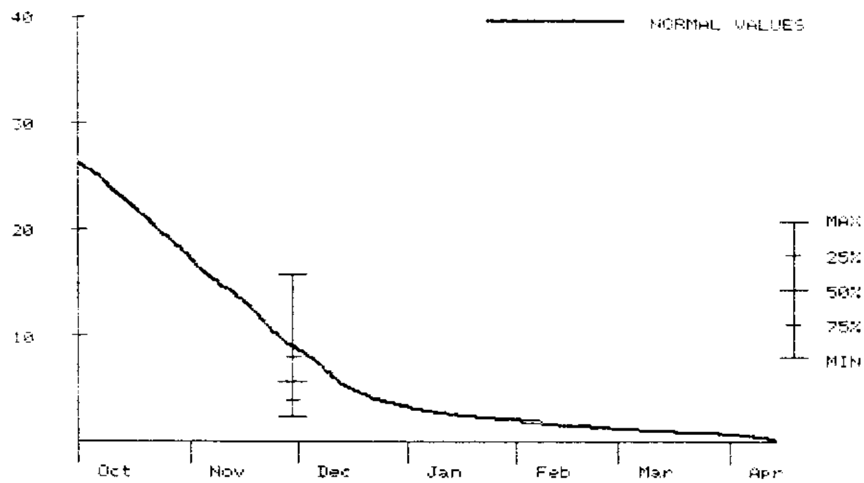
CRONOLOGICAL ORDER

Seq nr	Year	Peak m3/s	Month /Day
1	1977	629	12 11
2	1978	381	12 11
3	1980	832	1 1
4	1981	317	4 16
5	1981	1103	12 11
6	1982	159	11 30
7	1983	595	12 5
8	1984	191	11 30
9	1985	907	12 7
10	1986	157	11 30
11	1987	296	12 8
12	1988	433	12 4

ORDER OF MAGNITUDE

Year	Peak m3/s	Month /Day
1981	1103	12 11
1985	907	12 7
1980	832	1 1
1977	629	12 11
1983	595	12 5
1988	433	12 4
1978	381	12 11
1981	317	4 16
1987	296	12 8
1984	191	11 30
1982	159	11 30
1986	157	11 30

Figure 21. A long range forecast of the inflow to Lago Bayano for the period 1989-11-30--1990-04-15 based on input data from the corresponding dates during the preceding 12 years. The upper figure shows the different simulations and below the peak values are tabulated.



Forecast 1989 11 30 using data from the 12 previous years

VOLUME UNIT: accumulated daily mean discharge in m3/s

DATE	MIN	75%	50%	25%	MAX	DIFF(50%)
12 7	892	1086	1468	2283	4248	196
12 17	1570	2502	3595	4784	8014	105
12 27	1952	3286	4368	6493	10817	57
1 6	2153	3992	4780	7468	12505	32
1 16	2236	4157	5053	7854	14150	29
1 26	2265	4217	5246	7977	14797	12
2 5	2281	4219	5320	8016	15100	4
2 15	2282	4188	5334	8051	15215	1
2 25	2241	4145	5338	8031	15351	-1
3 6	2179	4134	5322	8010	15383	0
3 16	2090	4065	5460	7973	15354	2
3 26	1991	3986	5473	7907	15288	1
4 5	1937	3905	5491	7958	15204	-2
4 15	**2181**	**3894**	**5641**	**7932**	**15752**	**NORMAL VOLUME: 8793**

ACCUMULATED VOLUME LAST DAY

CRONOLOGICAL ORDER Year	Volume	ORDER OF MAGNITUDE Year	Volume
1978	5419	1982	15752
1979	5035	1980	10194
1980	10194	1984	8434
1981	6512	1986	7765
1982	15752	1981	6512
1983	2181	1989	5863
1984	8434	1978	5419
1985	2272	1979	5035
1986	7765	1988	4435
1987	2230	1985	2272
1988	4435	1987	2230
1989	5863	1983	2181

Figure 22. A long range forecast of the inflowing volume to Lago Bayano for the period 1989-11-30--1990-04-15.

9. DISCUSSION AND CONCLUSIONS

The project on "Streamflow Forecasting and Flood Warning in Central America" has aimed at establishing a flood warning system on the national level as well as to promote regional cooperation. One river in each of the countries of Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama has been selected for the project. The flood warning system based on the HBV runoff model has been calibrated and adapted to each of the rivers. Twelve Central American engineers have been trained in the use of the HBV model system.

The six river basins that were selected for the project differ very much in size, topography, vegetation and land use. The calibration results also vary and generally the small river basins, and basins with uneven precipitation were more difficult to model. In general the results were satisfactory, but in some of the countries the calibration of the model was complicated due to poor data quality. The calibration results for each country are discussed in more detail in the chapters on the individual countries.

The HBV model has been applied in many countries all over the world and in climates ranging from artic to tropical. It has proved to give good results in spite of a relatively simple structure (WMO, 1986). In Latin America, the model has earlier been calibrated and installed in Costa Rica (Johansson, Persson, Sandberg and Robles, 1985), Bolivia (Johansson, Persson, Aranibar and Llobet, 1987) and Colombia (Häggström, Lindström, Sandoval and Vega, 1988). In the application to the six Central American basins, we feel that the calibration results have been more dependent on the quality of the input data than on the model structure.

Most of the rivers in this project flow through steep areas, and the response time is short. A proper description of flood damping due to inundation is in most cases not critial. To be able to utilize the forecast it is sufficient with knowledge about the flood problems that are caused by different discharge magnitudes. Flood-risk maps are useful complements for the estimation of flooded areas for a given calculated discharge.

The conditions and possibilities for real-time forecasting vary much between the participating countries. A network for real-time transmission of precipitation data, really only exists in Panama at the time being. In Costa Rica, a similar system is being installed. Generally, more effort needs to be spent on rapid collection of both precipitation and streamflow data to make real-time flood forecasting possible and meaningful. The streamflow data are needed in order to check that the model state at the beginning of the forecast corresponds to the real conditions. To minimize the costs, a few stations in each of the river basins can be selected and equipped with telephone or radio communication. Both in Panama and Costa Rica, the model was recalibrated with fewer precipitation stations representing the real-time networks. The results were quite acceptable also with these reduced networks.

The possibility to use the HBV model for forecasting also depends on the response time of the basin. Some of the modelled basins are relatively small and the response to rainfall can occur very quickly, making forecasting rather difficult. In some of the basins a daily time-step is not sufficiently short and the model should be run with for example six hours time-steps. This has been tested in both Guatemala and Costa Rica. The problems with short time-steps is the data transfer in real time, the increasing data amount and the limited number of stations with such a time resolution.

Quantitative precipitation forecasts are in general rather unreliable. At the Central American institutions involved in this project, such forecasts are not produced or used on a routine basis. However, even without reliable forecasts of precipitation, the HBV model can be useful for flood warnings, since it keeps track of the present wetness status in the basin and thus give an indication of the flood risk. When no quantitative precipitation forecast can be obtained, a probabilistic precipitation forecast or even a qualified judgement by a meteorologist can be used.

Besides for flood forecasts, the HBV model can be used for many other purposes. In some of the countries, a major interest in the selected basin is to make long range volume forecasts. Such forecast can be used for optimization of the reservoir regulation or assessments of the resources available for irrigation during dry periods. The model can further be used for a check of discharge data, and filling in gaps in the records, as well as for extension of short runoff records for design purposes. The model also has a potential for simulation of groundwater levels (Bergström and Sandberg, 1983), soil moisture conditions (Andersson, 1988) or the effects of clear-cutting (Brandt, Bergström and Gardelin, 1988).

The HBV model can be used for spillway design (Bergström, Lindström and Sanner, 1989). An estimate of the PMP (Probable Maximum Precipitation) can be used as input and the model converts the design precipitation to a design inflow hydrograph. The inflow is then routed through the reservoir and further downstream, and the model can be used for design calculations in a whole system of reservoirs. The method is useful for the design of spillways of new dams and for the evaluation of the risk of overtopping of existing dam structures. If the model is to be used for design calculations, effort must be spent on checking its performance for high peaks.

Thanks to the simplicity of the HBV model, it is quite easy to understand and learn. The data requirements are also moderate. A two month training course gives the necessary background for an operational use of the forecasting system. However, the course could preferably be repeated with new participants to increase the total knowledge in each country and thus guarantee that a sufficient number of people are trained for a continued use of the model and its application to other river basins. The limited resources needed for using the HBV model means that it has a potential for becoming a valuable hydrological tool in Central America.